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R&T Number: 4222036---06

Contract/Grant Number: N00014-92-J-1121

Contract/Grant Title: Experiments on the Physics of Turbulent Mixing in Stably Stratified Ocean Layers

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Our research goals are to understand, quantify, and parameterize mixing processes in stably stratified fluids. The research is intended to provide a sound scientific basis for making accurate quantitative estimates of ocean mixing from limited observations at sea.

## II-Objectives

Our immediate objectives are to understand and quantify mixing in several different types of turbulent shear flows which are encountered in the ocean. Then we ask ourselves the question: If one had only limited data, such as that obtained from dropsondes or towed bodies, could one accurately predict the mixing rates? The answer will depend on the universality of the results for different flows when put in terms of dimensionless parameters.

## III-Approach

Our approach has been to carry out laboratory studies in topographically constricted flows, homogeneous turbulent shear flows, two steam mixing layers, and wake flows. A combination of water and air flow facilities are employed to isolate effects of varying Prandtl and Schmidt number.

## IV-Tasks Completed

- a. The effect of spatially varying Brunt-Vaisala frequency on the evolution and mixing of decaying turbulence was studied by Dr. Sigurdur Thoroddsen.

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b. A new mixing layer facility was built to replace our old one, which was too narrow to achieve sufficiently two-dimensional flow. The new facility produces flows with excellent lateral uniformity and has very low noise.

c. A continuous gradient stratified shear layer facility has recently (last month) been completed. The initial mean profiles of density and velocity look very good. Graduate student Paul Piccirillo made his first data run on Feb 3.

#### V-Scientific Results

a. The spatially varying N results showed that increasing N in the flow direction caused an initial quenching of the vertical velocity fluctuations and diapycnal fixing, but the ensuing restratification process caused the velocity fluctuations to increase further downstream. Yamazaki and Gerz have called this "zombie turbulence". These and other results show that the restratification process must be very important in ocean mixing.

b. Stable stratification is found to flatten and change the circulation of mixing layer streamwise vortices. This is illustrated in the enclosed photos (Fig. 1) comparing unstratified (1a) and stably stratified (1b) runs. For  $Ri$  as small as 0.04 there is a strong effect of buoyancy forces on the streamwise vorticity. The mixing transition (the breakdown when the transport abruptly increases with increasing Reynolds number) may be sensitive to the associated baroclinic generation of vorticity.

c. The data from the first stratified run in the continuous gradient facility, made with linear temperature and velocity profiles, look very good. The evolution of fluctuations, buoyancy flux, etc. looks even smoother than expected. With a Richardson number of 0.16 the turbulence level decreased very slowly, indicating that for this first run we were near the critical Richardson number.

#### References :

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P Thoroddsen, S.T. and Van Atta, C.W.: 1992 "The Influence of Stable Stratification on Small-Scale Anisotropy and Dissipation in Stably Stratified Turbulence," J. Geophysical Research, Oceans, Vol. 97:C3, 3647-3658.

P Thoroddsen, S. and Van Atta, C.W. :1992, "Exponential Tails and Skewness of Density-Gradient PDF's in Stably Stratified Turbulence", J. Fluid Mech. 244, 547-566.

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- P Thoroddsen, S.T. and Van Atta, C.W. 1992, "Experimental evidence supporting Kolmogorov's refined similarity hypothesis", Phys. Fluids. A 4(12), pages 2592-2594.
- PS Thoroddsen, S.T. and Van Atta, C.W. 1993 Wavelet Analysis of Turbulent Mixing in a Stably Stratified Fluid, submitted to proceedings of Wavelets Conference, Princeton.
- PS Yap, C. and Van Atta,C.W. 1993 An Experimental Study of Quasi Two-dimensional Turbulence in a Stably Stratified Fluid, Dynamics of Atmospheres and Oceans
- PS Thoroddsen, S.T. and Van Atta, C.W. 1993 The Influence of Grid Configuration on the Evolution of Decaying Turbulence in a Stably Stratified Fluid, Dynamics of Atmospheres and Oceans
- PI Thoroddsen, S.T. and Van Atta, C.W. 1993 The Effect of a Streamwise Increase in Brunt-Vaisala frequency on the Evolution of Decaying Turbulence

**Statistics:**

- 1) [3] Papers published, refereed journals
- 2) [1] Papers submitted or in press, refereed journals
- 3) [0] Books or chapters published, refereed publication
- 4) [0] Books or chapters submitted, refereed publication
- 5) [0] Invited presentations at scientific conferences
- 6) [5] Contributed presentations
- 7) [0] Technical reports and papers, non-refereed journals
- 8) [1] Undergraduate students supported\*
- 9) [3] Graduate students supported\*
- 10) [1] Post-docs supported\*
- 11) [1] Other professional personnel supported\*

\* supported means at least 25% support on this ONR grant

**EEO/Minority Support:**

- 12) [0] Female grad students
- 13) [0] Minority grad students
- 14) [1] Asian grad students
- 15) [0] Female post-docs
- 16) [0] Minority post-docs
- 17) [0] Asian post-docs

Minorities include Blacks, Aleuts, American Indians and Hispanics only.



Fig 1a. Fluorescene dye visualization of streamwise ( in the flow direction) vortices which wind themselves around the Kelvin-Helmholtz billows. Unstratified case ( $R_i=0.0$ )



Fig 1b. Same as 1a except now  $R_i=0.04$ . Note how streamwise vortices are compressed in the vertical direction compared with 1a.